RADIONUCLIDES IN SEDIMENT AT NUCLEAR FACILITIES IN GEORGIA

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Abstract. As part of its environmental radiological surveillance program, the Georgia Department of Natural Resources monitors man-made radionuclides in sediment below the outfalls of nuclear facilities. Sediment acts as a water contaminant indicator and accumulator, and as a potential source of these contaminants for aquatic biota. Locations in the Chattahoochee R., Savannah R., Altamaha R., Etowah R., and Cumberland Sound have been monitored for up to 20 years. Samples typically are collected once per year at designated stations for analysis of photon-emitting radionuclides and, in some cases, Sr-90 and Pu-239. Most samples contained only naturally occurring radionuclides and some residues of fallout from atmospheric tests of nuclear weapons. Reported here are the relatively low levels of radionuclides attributed to facility discharges that occasionally were detected. Results were combined with radionuclide amounts reported in facility effluent and concentrations measured in water and fish to calculate radiation doses to the potential maximally exposed persons. These annual doses by the aquatic pathway were very low in most cases and below the regulatory limits in all cases.

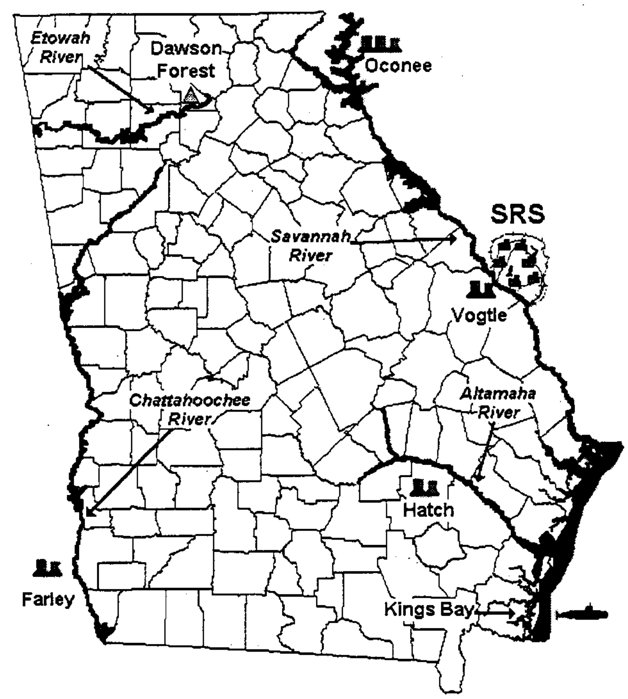

Figure 1. Nuclear facilities monitored at Georgia rivers.

INTRODUCTION

As part of its environmental radiological surveillance program, the Georgia Department of Natural Resources (DNR) monitors man-made radionuclides below the outfalls of nuclear facilities (Rosson et al. 1993). The bodies of water shown in Fig. 1 and listed in Table 1 have been monitored continuously for up to 18 years by sampling and analyzing water, fish, and sediment. Reported here are the results of measuring photon-emitting radionuclides, ^{90}Sr, and plutonium in sediments. The facility operators also report monitoring results as well as radionuclide discharges.

Sediments are monitored at the facilities listed in Table 1 mainly as sensitive indicators of radionuclides in the aquatic system. The sediments accumulate soluble radionuclides by sorption on suspended sediment and insoluble radionuclides by settling. Any inferences from measurements are qualitative because distribution of radionuclides between water and sediments depends on the combined characteristics of the sediment, the water, and the radionuclides. Moreover, contaminated materials may move downstream or be covered by other materials.

Photon-emitting radionuclides can expose persons to external radiation when little or no water covers the sediment, e.g. at the banks. Radionuclides in sediment also are not direct sources of internal exposure to persons but may be indirect sources if taken up by fish or released to waters that are then ingested by humans.

Many of the sediment samples were found to contain fission-produced ^{137}Cs; a few contained fission-produced

Table 1. Sediment Monitoring Sites

Aquatic System	Facility	Operation	Activity
Savannah River:			
SRM 158-125	Savannah River Site	1954-	^{3}H / Pu Production
SRM 150	Vogtle Electric Generating Plant	1987-	2-unit PWR
Altamaha River	Hatch Nuclear Plant	1975-	2-unit BWR
Chattahoochee River	Farley Nuclear Plant	1977-	2-unit PWR
Etowah River	Dawson Forest ... formerly Georgia Nuclear Aircraft Lab	1958-1971	Former 10 MW Test Reactor
Cumberland Sound	Kings Bay	1979-	Submarine base
Lake Hartwell	Oconee Nuclear Station	1973-	3-unit PWR

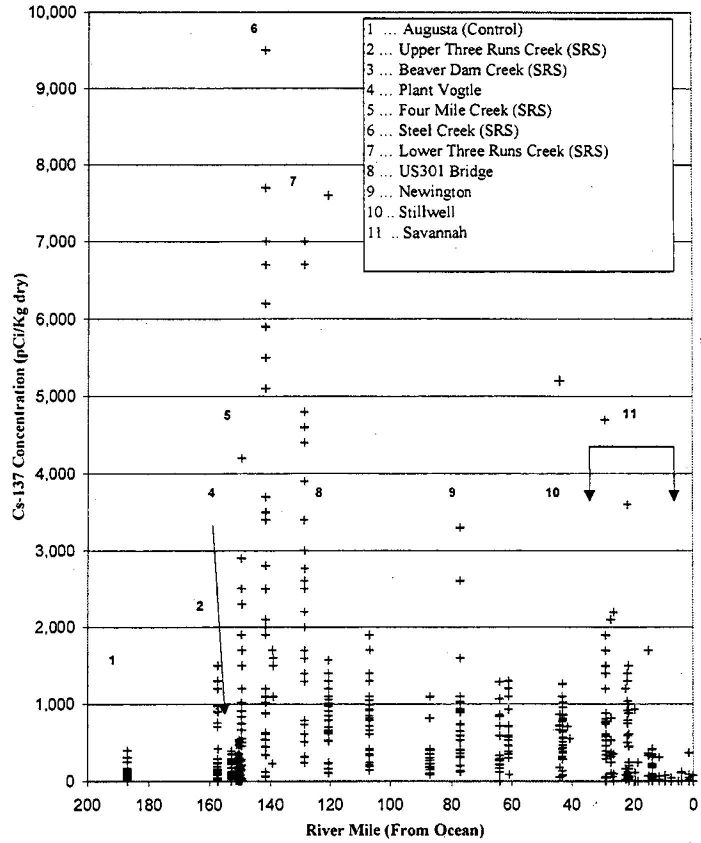

Figure 2. Cs-137 in Savannah River sediment vs. river mile from ocean.

^{90}Sr and ^{134}Cs, activation-produced ^{60}Co, ^{58}Co, ^{54}Mn, and ^{65}Zn, and the transuranium isotopes ^{239}Pu and ^{241}Am. These radionuclides are attributed mostly to discharges at the monitored facilities. Some ^{137}Cs, ^{90}Sr, and ^{239}Pu are fallout from nuclear tests in the atmosphere, which peaked in 1962 - 1963 and -- to a minor extent -- from the nuclear accident at the Chernobyl reactor in April 1986. Naturally occurring radionuclides -- uranium plus progeny, thorium plus progeny, and ^{40}K -- also were detected. Many of the measured values are near the limits of detection.

MONITORING

Samples are collected in rivers above, at, and below the following sites: the Savannah River Site (SRS) plus Plant Vogtle, Plant Hatch, and Plant Farley. Locations were selected upstream as controls; at the sites, to monitor specific outfalls; and downstream, to examine patterns of radionuclide deposition and movement. Other sampling points are around the Kings Bay nuclear submarine base in Cumberland Sound at the Atlantic Ocean; below Oconee Nuclear Station on Lake Hartwell, and near the site of a dismantled test reactor in Dawson Forest.

The DNR collects sediment samples annually. A Ponar dredge is lowered to the bottom of the water body, where its jaws are closed on sediment by remote control. In addition, nuclear facility staffs share with DNR the samples that they collect yearly in spring and fall. Sufficient sediment is collected for a 600-cc sample. Locations are identified by river mile above the mouth, e.g., Savannah River Mile (SRM) 150, or below the facility at non-navigable reaches of rivers.

Additional samples have been collected in response to reports of unusual releases such as leakage from the fuel pool in 1986 at Hatch. A brief study was performed in the Ogeechee River just to the south of the Savannah River to check elevated ^{137}Cs in sediment near river mouths.

At the laboratory, the samples are weighed and an aliquot is dried at 105° C so that radionuclide results can be reported in terms of dried weight. The 600-cc samples are measured for photon energy and intensity with a high-purity germanium detector and analyzed with a spectrometer. This analysis determines ^{137}Cs, ^{134}Cs, ^{60}Co, ^{58}Co, ^{54}Mn, ^{65}Zn, and ^{241}Am, as well as naturally occurring ^{226}Ra, ^{228}Ra, ^{238}U, and ^{235}U.

Aliquots of 1 to 3 gram are dried and dissolved with strong acid in a microwave oven. Strontium carrier with ^{90}Sr is separated for counting beta particles emitted by

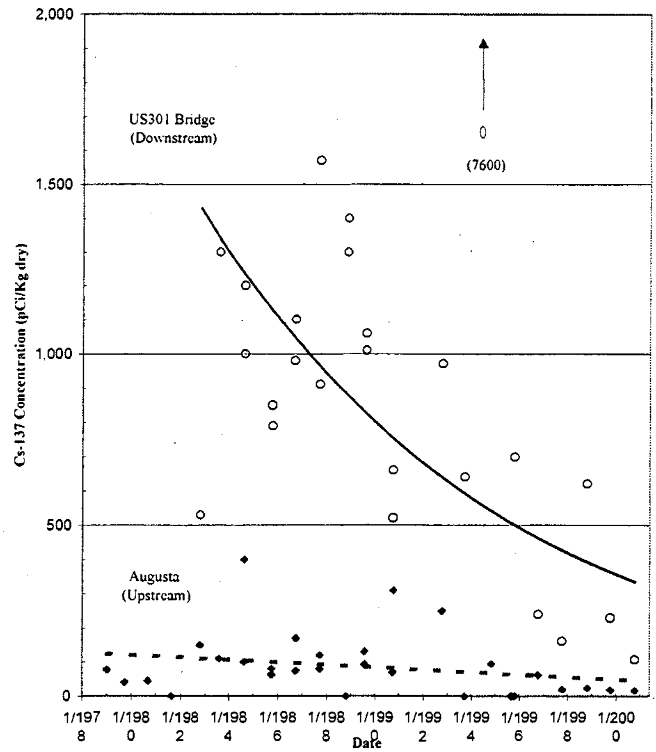

Figure 3. Cs-137 trends in Savannah River sediment upstream and downstream of SRS and Vogtle.

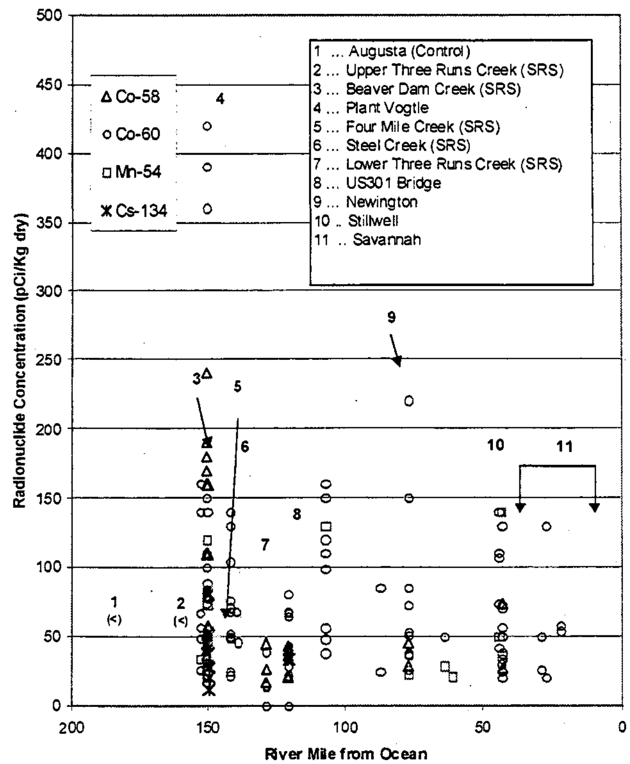

Figure 4. Radionuclide concentrations in Savannah River sediment downstream of SRS and Vogtle.

^{90}Sr. A radioactive tracer is added to the samples to be analyzed for ^{239}Pu and ^{238}Pu, and the samples are purified and electrodeposited. The alpha particles are counted with a silicon detector and the spectrum is analyzed with a spectrometer to identify specific isotopes and determine their activity. The activity is adjusted for chemical yield on the basis of carrier or tracer measurement.

Detection limits are approximately 10 picocurie/kilogram (pCi/kg) for photon-emitting radionuclides, 500 pCi/kg for ^{90}Sr, and 2 pCi/kg for ^{239}Pu. The latter may also include ^{240}Pu, which has alpha particles of the same energy. The counting efficiencies are determined by calibrating with radioactive standards traceable to National Institute of Standards and Technology. The detection systems are checked at frequent intervals for background count rates and consistency of efficiency and energy responses.

All results are stored in computer files maintained by DNR and published in annual reports (DNR 2000). The data for sediment are summarized in this report.

RESULTS AND DISCUSSION

SRS/Vogtle. ^{137}Cs was detected in a majority of the sediment samples collected in the Savannah River since 1982. Highest concentrations were in the mouths of three creeks through which SRS discharges low-level radioactive waste, as shown in Fig. 2 at locations # 5, 6, and 7. Values varied among samples collected at a location for various reasons: fluctuating radionuclide discharges, movement of contaminated sediment, accumulation of uncontaminated sediment, differences among samples in the fraction of the clays that most effectively retains cationic radionuclides, and difficulties in replicating the exact sampling site.

The higher ^{137}Cs concentrations in sediment at SRM 20 to 30 compared to farther upstream were consistent with the findings near the mouths of the Ogeechee and Altamaha Rivers (see below). This increase is believed to be caused by flocculation of ^{137}Cs-bearing suspended sediments where fresh water mixes with sea water.

The ^{137}Cs concentrations in Savannah River sediment decreased over time, especially since 1987 (with one unexplained exception), as shown in Fig. 3. Decreases at the upstream control site reflect the gradual reduction of fallout. Downstream decreases are attributed to a major reduction from earlier years of SRS discharges. ^{134}Cs, which has a shorter half life than ^{137}Cs (2.06 y vs. 30 y), was found at only one location (SRM 365) in 1989 and 1990.

Plutonium (^{238}Pu and $^{239/240}Pu$) was found only at six sampling sites at and below SRS in the period 1993-1999. The highest concentration was 60 pCi/kg. ^{241}Am at barely detectable levels was found at two of these locations. ^{90}Sr was detected in only one sample well downstream from SRS/VEGP (SRM 27) in 1994. Elevated ^{226}Ra was observed at SRM 160 and 150 in the range of 4,900 to 13,000 pCi/kg in the period 1996 - 1998; these levels are much higher than the usual background of 800 - 2,400 pCi/kg in this reach of the river.

Both separately and combined, ^{60}Co, ^{58}Co, and ^{54}Mn (and rarely, ^{134}Cs) were at location 4 and downstream since 1986 (see Fig. 4). Concentrations generally decreased downstream, and none of the radionuclides were found upstream. These radionuclides were produced at SRS before 1988 and at Vogtle since 1987, hence relatively short-lived ^{58}Co and ^{54}Mn can be attributed to the facility that produced them at the time. Some ^{60}Co was found in sediment before Vogtle began operating. No pattern with time was observed.

Hatch. Only a few samples had ^{137}Cs concentrations above the control values of 600 to <10 pCi/kg, as shown in Fig. 5. These were at and just below the Plant Hatch outfall in the period 1985 - 1990. That concentrations were generally higher at Darien, about 10 mi. from the mouth of the Altamaha River than farther upstream at Jesup is consistent with the observations in the Savannah and Ogeechee Rivers cited above.

The radionuclides ^{134}Cs, ^{65}Zn, ^{60}Co, and ^{54}Mn have been found consistently in the Altamaha River below the Hatch discharge since 1986. The highest concentration of any single radionuclide was 660 pCi/kg but most concentrations were considerably lower, as shown in Fig. 6. None of these radionuclides was detected at the control location upstream from the discharge.

Farley. The radionuclides ^{60}Co, ^{58}Co, and ^{54}Mn were detected from 1996 to the present at four sampling locations in the Chattahoochee River from the Plant Farley outfall to 15 mi. downstream. These radionuclides

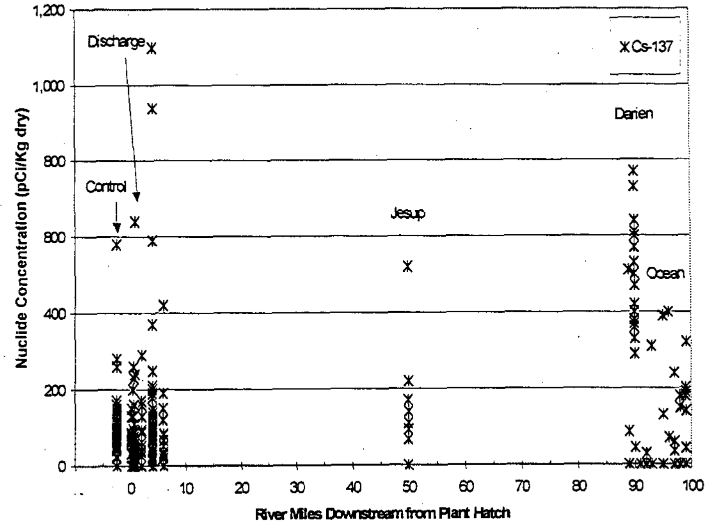

Figure 5. Cs-137 concentration in Altamaha River sediment downstream of Plant Hatch.

were not detected earlier, or at the upstream control location. Concentrations of ^{137}Cs were between 100 and <10 pCi/g upstream and between 120 and <20 pCi/g downstream, hence any contribution by FEGP was small.

Oconee. Lake Hartwell sediment, collected from 1989 to the present at a background site, upstream from the confluence with the Seneca River arm into which Oconee Nuclear Station discharges, had ^{137}Cs concentrations between 130 and <10 pCi/kg. Samples collected from three locations at the mouth of this arm had ^{137}Cs concentrations between 1,050 and 40 pCi/kg. Concentrations in samples collected further downstream, just above Hartwell Dam, were between 180 and 40 pCi/kg. None of the other photon-emitting radionuclides cited above were found in any of the samples. More detailed studies of radionuclides in Lake Hartwell have been reported (Fjeld and Elzerman 1986).

Kings Bay. The only man-made radionuclide detected by photon spectral analysis in Cumberland Sound sediment at 13 locations near the submarine base waterfront area between 1982 and the present was ^{137}Cs at concentrations between 600 and <10 pCi/kg. At 3 locations in the mouths of rivers 2.5 to 4 mi. distant, concentrations were between 120 and <10 pCi/kg. Although the higher concentrations may suggest that some ^{137}Cs was discharged at the facility, similar sediment concentrations in the ocean at the Savannah and Altamaha Rivers shown in Figs. 2 and 6 indicate fallout as the ^{137}Cs source.

Dawson Forest. No ^{137}Cs, ^{60}Co, or ^{152}Eu was detected (<10 pCi/kg) in the Etowah River at the Dawson Forest

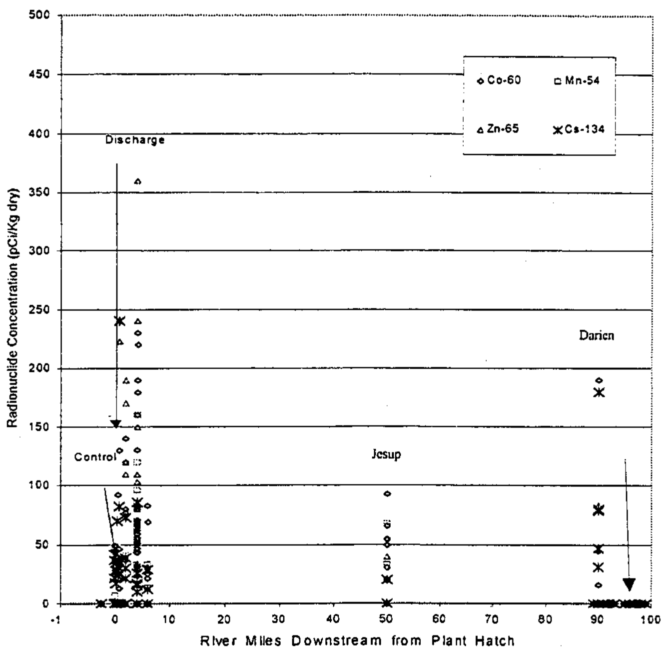

Figure 6. Radionuclide concentrations in Altamaha River sediment downstream of Plant Hatch.

Wildlife Preserve, either downstream or upstream from the former reactor test site, from 1980 to the present. These radionuclides have been found in the remains of various structures that are within 0.3 mi. of the river. They also were at concentrations up to 1,300 pCi/kg in sediments collected from a small swamp below the reactor area and from a small creek at the cooling-off area that empties into the Etowah River.

Radiation Dose Impact on Persons. The radiation dose to the most exposed person from each of the nuclear power stations by the aquatic pathway typically is of the order of 0.1 mrem per year. The dose calculation is based on radionuclide discharges in liquid effluent and should consider all possible exposure pathways, such as consuming aquatic animals and using the water for drinking, irrigation, and recreation (Southern Company 2000). At SRS, the calculated dose is about 1 mrem per year due to fish consumption and 0.1 mrem per year from water intake (Arnett and Mamatey 1999). In comparison, the regulatory limit is 100 mrem per year. The concentrations of radionuclides in sediments reported here do not have the potential for exposures above the cited calculated values. No radionuclides attributable to the sites were found at the sediment monitoring locations for Kings Bay and Dawson Forest; an annual report with information on monitoring and radioactive waste disposal is provided by Kings Bay (Mangeno et al. 2000).

CONCLUSIONS

Sediments are collected by the Georgia DNR from waters at six active facilities and one dismantled nuclear site as indicators of radionuclides released in liquid effluent. Several radionuclides have been detected in sediment. At four of the facilities, such radionuclides in sediment at low concentrations can be attributed to discharges. Some radionuclides are believed to originate both in liquid effluent and fallout. These radionuclides in sediment do not constitute a health hazard, but permit tracing the movement of effluent for many miles. This program will continue.

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